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Records of Oscillations in Lake Level and Records of Lake Temperature, and of Meteorology, Secured at the Macbride Lakeside Laboratory, Lake Okoboji, Iowa, July, 1915

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RECORDS OF OSCILLATIONS IN LAKE LEVEL AND RECORDS OF LAKE TEMPERATURE, AND OF METEOROLOGY, SECURED AT THE MACBRIDE LAKESIDE LABORATORY, LAKE OKOBOJI, IOWA, JULY, 1915.

JOHN L. TILTON.

At the Macbride Lakeside Laboratory, Milford, Iowa, the writer began a series of observations last summer (1915) for his own information to ascertain what the fluctuations were in the level of the lake, and to determine the relative value of the causes that operated to produce those fluctuations. It soon became evident that the records sought were desired also by teachers in other departments because of the bearing of such data on life zones and conditions in the lake. Since then the government has called for all data available on evaporation in Iowa. The data are therefore here presented that they may be of immediate use and on file for future reference.

To detect the oscillations in the level of the lake it first became necessary to devise a piece of apparatus for that purpose. A closed hollow cylinder two inches in diameter was placed as a float in a larger cylinder three inches in diameter, closed at the bottom. Through the sides of this outside tube a few nail-holes were punched to let in the water slowly so that the float inside of this tube would rise and fall gradually but not move perceptibly for small waves. This was placed in a vertical position in the water close to the boathouse where the water was about four feet deep. It was found that waves five or six feet from crest to crest and perhaps a foot from trough to crest would move the float about the twentieth of an inch. When a steamer made a landing the float would rise and fall about three-eights of an inch. To an upright rod fastened to the float a thin strip of brass was attached, on the end of which was a pen which traced all vertical movements on a cylinder that revolved once a week by clock work. The revolving cylinder, the pen and penholder, were parts of a thermograph which was thus made to serve present purposes.

As might be expected the tidal effect (estimated at .0016 inch) could not be detected at all in a direct reading device of this kind; but the conditions involved deserve attention. The distance from the laboratory to Arnold's Park (west to east) is

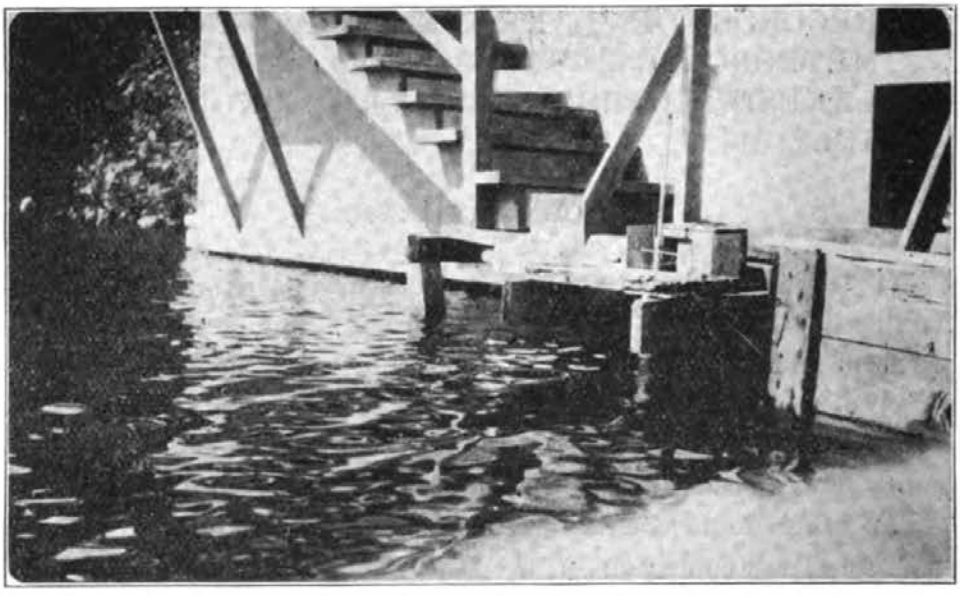


FIG. 4—The recorder of variations in the level of the lake.

two and three-fourths miles. From this line north to the head of the lake the distance is three and a half miles, approximately the same as the east and west stretch of water. When the east and west stretch alone is considered it should be low tide when the moon rises and high tide when the moon sets, with neutral effect when the moon is on the meridian. When the north and south stretch alone is considered it should be high tide when the moon is on the meridian, with neutral effect when the moon rises and when it sets. Thus even these minute differences almost exactly neutralize each other.

Oscillations due to changes in barometric pressure were also too minute to be detected by direct registration without magnification. One of several computations made to ascertain the magnitude of such oscillations resulted as follows: On June 30 the weather map gave a barometric pressure of .00041½ pounds per square inch at West Okoboji (at the north end of the lake) in excess of that at the laboratory, which pressure would be counterbalanced hydrostatically by a rise of .00095 inch in the level of the lake at the laboratory. This difference in barometric pressure was one of the most marked differences that occurred during the period of observation.

The inflow at the head of the lake, and the outflow over the dam were not gauged, but by inspection they were judged fairly to compensate each other.

The main changes in level were due to evaporation, to precipitation and to strong winds. For each continuous period of evaporation without strong wind there was a steady drop in the level of the lake of from .1 to .3 inch per day. A similar effect of evaporation was detected when from the height marked by the gauge the rise due to precipitation was subtracted. The records of evaporation and of precipitation were obtained from a glass battery jar about eight inches in diameter and eight inches high placed over the lake and about a foot above it.

The rise due to precipitation was very evident, at one time carrying the pointer above the cylinder. (The rise due to precipitation may be seen in the records for July 6, 11, 15, 19, 26 and 30. Apparently friction slightly interfered with the freedom of motion of the pen the first week.)

The total drainage area of the lakes West and East Okoboji estimated from the county map of the Iowa Geological Survey is fifty-five square miles; the area of the lake itself eight and four-tenths square miles. One inch of rainfall over the drainage area would raise the level of the lake 6.55 inches if all of the precipitation were to reach the lake. Evidently much of the precipitation would soak into the ground and later be evaporated without reaching the lake at all. Precipitation is generally unevenly distributed over the area in thunder storms, and the immediate effect on the level interfered with by the wind. In one instance precipitation of 1.2 inches at the point of observation was actually accompanied by a fall in the level of the lake at that point.

Rise and fall due to the wind was not so great as was expected, for the crests of the waves under strong wind pressure present a deceiving appearance. Apparently the differences in level due to the wind are quickly relieved by a general compensating movement in the lake. In general a strong wind from the southwest, west and northwest causes a slight fall in the level of the surface of the lake at the laboratory, while a strong northeast, east and southeast wind causes a corresponding rise in the surface at the laboratory. Effects of the wind in lowering the level of the lake at the laboratory may

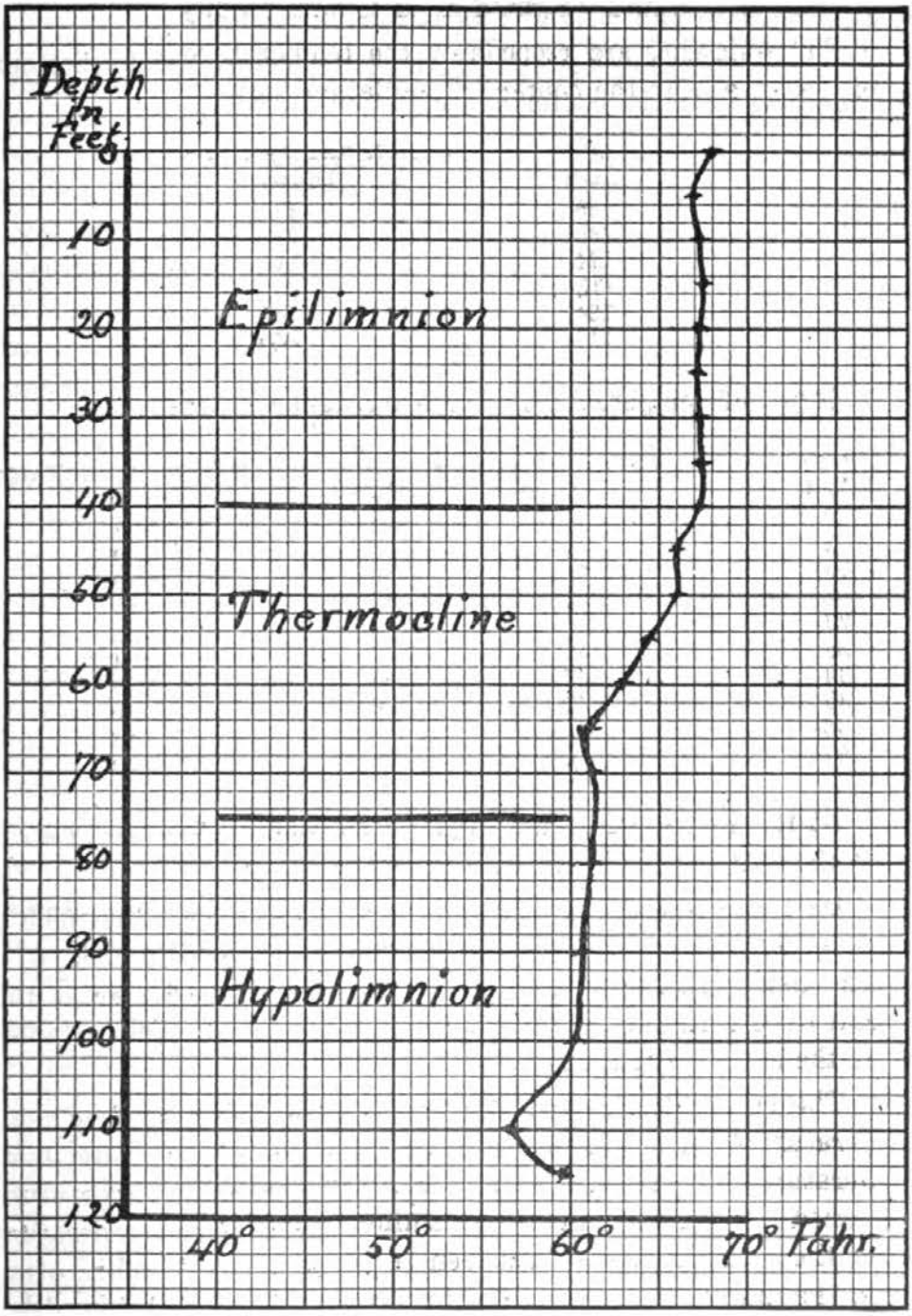
be seen in the record for June 29, July 1, 10, 11, 14, 16, 19, 20, 25. Effects of the wind in raising the level of the lake at the laboratory may be seen in the record for July 9, 12, 16 and 28. The effect of large waves superimposed on the effects of evaporation, precipitation and wind are to be noticed in the tracing for June 29, 30, July 7, 12-14, 15 (very pronounced), 19, 20, 21, 22, 24-25, 27-28.

THE TEMPERATURE OF THE LAKE.

Three series of observations of the temperature of the lake were obtained: one at the end of the pier at the laboratory

FIG. 5—Apparatus used to ascertain the temperature of the water at different depths.

where the water was six and a half feet deep; one, half way between the pier and the spit and hook at the entrance to the bay; and one close to the center of oscillation of the lake, as



Temperature curve for Lake Okoboji, August 5, 1915.

near as possible to the place where the record of depth when the lake was surveyed was 132 feet. The records of temperature were taken by a minimum thermometer kept in a horizontal position and weighted so as to sink readily.

The following are records of the temperature at the bottom of the lake near the center of oscillation July 13:

Depth Feet	Temperature Fahr. Degrees
85	59
135	56
124	55
115	59
124	59
115	58½

Series of temperatures obtained August 5, 1915:

Depth Feet.	Temperature Fahr. Degrees.	Depth Feet.	Temperature Fahr. Degrees.
0	68.0	50	66.0
5	67.0	55	64.2
10	67.1	60	62.9
15	67.3	65	60.5
20	67.1	70	61.3
25	67.1	80	61.1
30	67.1	90	60.7
35	67.3	100	60.0
40	67.4	110	56.5
45	66.0	115	59.8

At the end of the pier at the laboratory: at surface, 68.7°; at the bottom, 67.1° (six and a half feet deep).

Half way between the pier and the hook: at the surface, 68.3°; at a depth of 5 feet, 67°; at the bottom, depth 10 feet, 67°. The daily observations of the temperature of the water at the end of the pier are recorded with meteorological data in tables at the end of this paper.

The observations at the end of the pier give a surface temperature of the water that follows the curve of maximum temperatures of the air. The curve of maximum temperature varied with the amount of sunshine. The surface temperature of the water fluctuated between 64° Fahr. and 75° Fahr., often in the morning toward the latter part of the month being above the temperature of the air at the time, and also above the temperature of the air during stormy weather. A day of bright sunshine with little wind produced a rise of a degree or two in the temperature of the surface water. In the evening the dif-

ference in temperature between the surface at the end of the pier and the bottom at the same place (six and a half feet deep) was sometimes as much as two degrees, at one time after a day of bright sunshine with little wind amounting to five degrees (July 12). Even this large difference in temperature was nearly equalized by circulation during the night. A little wind was commonly enough to bring in and down the warm surface water of the lake, or to blow out and away the warm surface water, causing the colder water below the surface to rise. The morning observations often gave the same temperature at the surface as at the bottom at the end of the pier, and but three times (July 5, 14 and 30) giving a greater difference than one degree. These were days of bright sunshine and little wind.

The data for the temperature curve of the lake were obtained the fifth of August, as late as it was convenient to gather the data. Unfortunately the entire week preceding that date was characterized by clouds, strong wind and somewhat of rainfall, which condition accounts for the irregularity noticeable in the curve of temperature. Even in this irregularity the planes of demarcation of the three zones are pronounced. The area of the hypolimnion extends from near Terrace Park northward through the central portion of the lake to opposite the center of Omaha Beach. The thermocline extends over this area and a little to each side of it from Terrace Park to Omaha Beach and then extends northward to opposite Pikes Point. It is to be noted that within the epilimnion (where the water is forty feet or less in depth) is included the waters of all the bays of West Okoboji, all of Lower, Middle and Upper Gar Lakes, and all of East Okoboji for which data on depth are recorded. The volume of water of West Okoboji included in the epilimnion at the time of observation, which was very nearly the maximum for the year,* is computed as approximately 171,540,503 cubic yards. The volume in the thermocline, twenty-five feet thick, is approximately 72,709,309 cubic yards, and the volume in the hypolimnion approximately 38,713,961 cubic yards. The above figures are based on the soundings made in 1905 by the engineering students of Iowa State College.

*Edward A. Birge and Chancey Juday, "A Limnological Study of the Finger Lakes of New York," Bulletin of the Bureau of Fisheries, Vol. 32, 1912, Document No. 791, page 546.

THE METEOROLOGICAL DATA.

The month of July, 1915, is reported to have been an unusually cold and rainy month for that time of the year. The maximum temperature ranged between 70° and 87° Fahr., and the minimum from 44° to 70.5° Fahr. The relative humidity varied from 52 per cent to 100 per cent, was often close to 100 per cent and very often above 90 per cent. The details of the data are in the tables that follow, and are made use of in the analyses of the curves.

COMMENTS ON PLATES III AND IIIA.

On June 30 the barometric pressure at the north end of the lake in excess of that at the laboratory was sufficient to cause a rise of .00095 of an inch in the level of the lake at the laboratory. The preceding day there was no difference in the barometric pressure at these two extremes, but there was a gradual fall in the level of the lake, suggesting the need of a record of precipitation, evaporation, intake and outflow. Observations on precipitation and evaporation were begun July 5.

July 1 the level of the water fell quickly a quarter of an inch on change of wind from southeast to northwest.

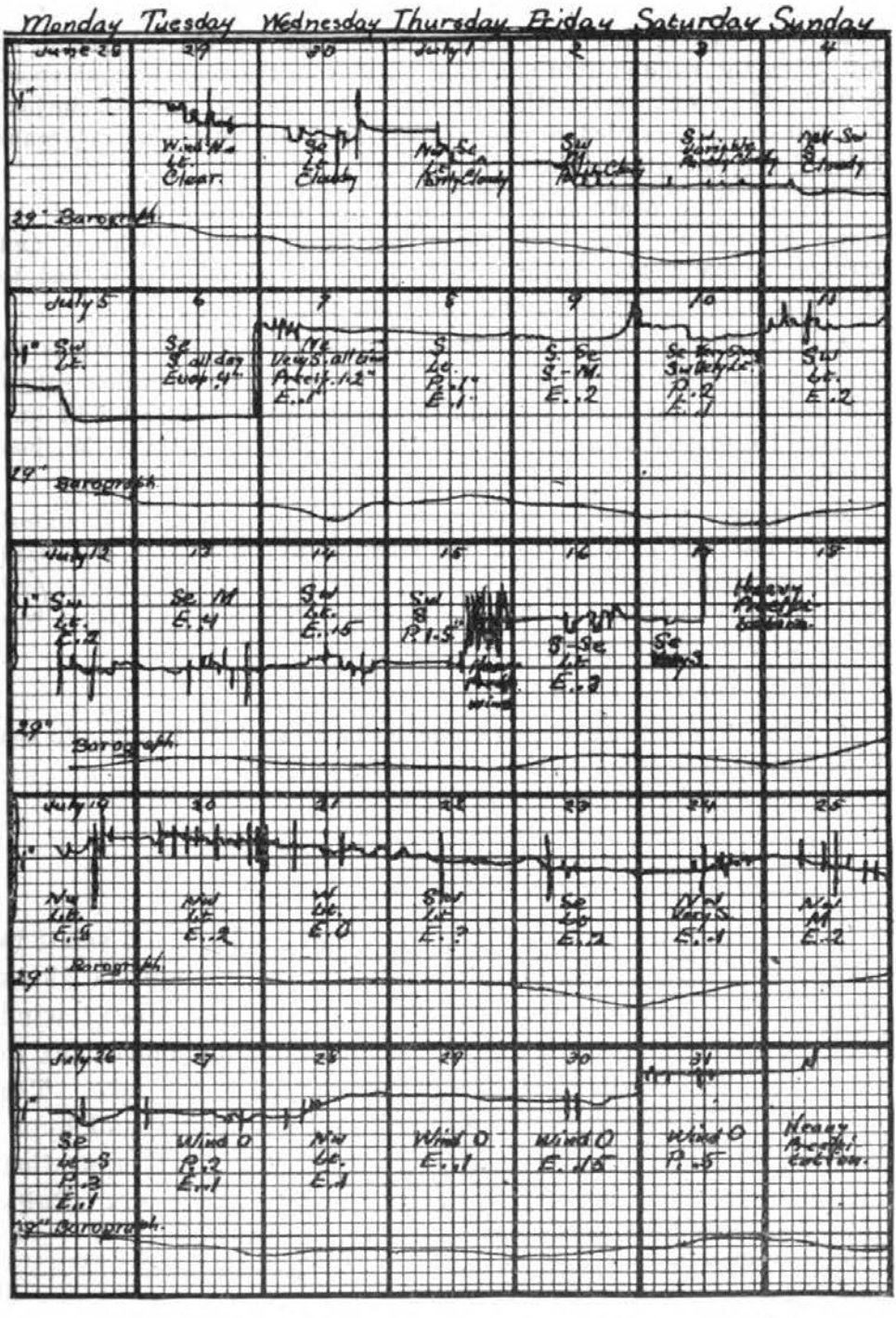
July 3 the excess of barometric pressure at the laboratory over that at north end of the lake should have caused a lowering of the water of .0021 of an inch at the laboratory and have maintained that difference that day and the next. To make such a variation evident the apparatus should magnify the movement at least thirty times, and preferably fifty.

July 5 a light southwest wind during the afternoon, aided somewhat by evaporation, sent the pointer below the bottom of the scale. July 7 the wind shifted to the northeast, and the water rose quickly one and one-half inches (from the bottom of the scale to that height), which level it maintained approximately for about three days.

July 7 the excess of barometric pressure at Arnold's Park over that at the laboratory would cause a rise of .015 of an inch.

July 8 the excess of barometric pressure at East Okoboji (north end of the lake) would cause a rise of .03 of an inch in the level of the water at the laboratory.

July 12-15. If allowance be made for evaporation the general course of the line is horizontal during a short period of clear weather with medium to light winds. There are, however, rythmic curves noticeable with a maximum variation of about one-fifteenth of an inch on the 12th, 13th and 14th, apparently due to variations in the wind; and also variations lasting from one to three hours amounting to 1-30 inch for which no suitable explanation is at hand. The long variations of ap-



Graphs of fluctuations in the level of the lake from June 28 to July 31, 1915. The heavy line gives the fluctuations and the light line the barometric pressure; other related data are included.

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proximately half an inch are thought due to waves caused as a steamer made a landing and left, as these lines were made in the daytime and at hours when the steamer was due.

July 15. There was a strong southeast wind till the rain began to fall; then the wind shifted and blew hard from the southwest at about 3:30 P. M. The precipitation amounted to one and one-half inches, but the gauge recorded a rise of only half an inch, the difference being due apparently to the strong wind.

July 16. The pronounced rhythm is not due to the effects of the storm because the line is straight from midnight to daybreak and straight again Friday night. It is possible the rhythm is due to changing winds of which there is no exact record.

July 17. There was heavy precipitation and changing winds of which there is no record, excepting as the heavy precipitation raised the pen above the revolving cylinder of the gauge (1 and 5-16 in.) Apparently there was a fall of 3-32 inch at eleven o'clock A. M., just before the rain came.

July 19-25. The graph is characterized by a constant and almost uniform lowering of the level of the lake due to evaporation, equalized by a somewhat strong northwest wind on the 24th, when the line traced became almost horizontal. The remainder of the week the wind was light and the barometric gradient zero.

July 26. The rise was due to precipitation.

July 28. The marked rise of three-tenths of an inch was due to the wind which then began to blow from the northwest.

July 30. The rise was due to precipitation.

SUMMARY.

Tidal effects were almost zero, barometric effects too small to be detected without magnification, and intake and outflow about equal. Wind effects were noticeable, and when strong wind was not prolonged, were quickly compensated by movement in the lake. The wind directed the circulation in the lake. The division of the lake water in epilimnion, thermocline, and hypolimnion was pronounced, even after strong winds. Evaporation amounted to about two-tenths inch per twenty-four hours. Rainfall caused an immediate rise in the hydrograph.

Table of Meteorological and Lake Data.

				7 A. M.					12 M.				7 P. M.				7 A. M.						7 P. M.					
	Max.	Min.	Wind	Vel.	Dry	Wet	Rel. Hum.	Dew Pt.	Dry	Wet	Rel. Hum.	Dew Pt.	Dry	Wet	Rel. Hum.	Dew Pt.	T. Top	T. Bottom	Wind	Veloc.	Prec.	Evap.	T. Top	T. Bottom	Wind	Veloc.	Prec.	Evap.
22	71	----	Nw	M	----	----	----	----	----	----	----	----	68	59	59	53	----	----	----	----	----	----	66	----	----	----	----	----
23	75	56	Sw	----	----	----	----	----	66	65	95	64	72	66	73	63	63	----	----	----	----	----	----	----	----	----	----	----
24	71	58	Nw	Lt	61	59.5	89	59	66	63	85	61	66	63	85	61	63.5	----	----	----	----	----	67	65.5	----	----	----	----
25	76	58	Sw	Lt	66	62	80	60	----	----	----	----	75	67	66	63	65	----	----	----	----	----	70	66	----	----	----	----
26	87	64	Se-Sw	St	69	66	85	64	----	----	----	----	77	67	59	62	70	65	----	----	----	----	71	65	----	----	----	----
27	83	62	Se	M	----	----	----	----	79	71	67	67	77	72	78	70	----	----	----	----	----	----	71	65	----	----	----	----
28	78	65	Se	Lt	----	----	----	----	75	69	74	66	75	69	74	66	69	67	----	----	----	----	69	67	----	----	----	----
29	76	58	Nw	Lt	62	59	84	57	----	----	----	----	66	62	80	60	66	63	----	----	----	----	69	68	----	----	----	----
30	75	55	Se	Lt	58	56.5	89	56	74	64	58	58	68	64	81	62	68.5	68	----	----	----	----	73	69.5	----	----	----	----
1	83	63	Nw-Sw	St Lt	65	61.5	59	59	82	69	52	62	68	63	76	60	71	69	----	----	----	----	71	69	----	----	----	----
2	70	52	Sw	M	57	54	82	52	67.5	58.5	59	52	61	55	68	50	68	67	----	----	----	----	69	69	----	----	----	----
3	74	47	Sw	Var	49	48	93	47	70	59	52	51	60	55	73	51	67	66	----	----	----	----	67	66	----	----	----	----
4	74	44	Nw-Sw	St	58	53	72	49	65	58	66	53	62	55	64	50	65.5	65	Nw-Sw	St	----	----	66	66	----	----	----	----
5	74	45	Sw	Lt	60	56	78	53	70	60	56	53	67	59	62	54	64	62	Sw	Lt	----	----	66	66	----	----	----	----
6	78	57	Se	St	62	60	89	59	75	68	70	64	74	69	78	67	64.5	64.5	Se	St	----	.15	69	66.5	Se	St	----	.25
7	74	64	----	----	64	64	100	64	63	62	94	61	63	62.5	98	62	67	67	Ne	St	1.2	----	68	66.5	Ne	St	----	.1
8	71	58	----	----	62	60	89	59	67	62	76	59	68	64	81	62	65.5	65	0	0	----	.1	68.5	67.5	S	M	.1	----
9	70	58	----	----	65	63	90	62	66	64	90	63	66.5	65	97	66	66.5	66.5	S	St	----	.1	68	67	Se	M	----	.1
10	80	61	----	----	66.3	66.1	98	65	72	69	86	68	75	72	86	71	66.5	66.5	Se	v'ry St	.2	----	68	66.5	Sw	Lt	----	.1

TABLE OF METEOROLOGICAL AND LAKE DATA.—Continued.

				7 A. M.					12 M.				7 P. M.				7 A. M.						7 P. M.					
	MAX.	MIN.	WIND	VEL.	DRY	WET	REL. HUM.	DEW PT.	DRY	WET	REL. HUM.	DEW PT.	DRY	WET	REL. HUM.	DEW PT.	T. TOP	T. BOTTOM	WIND	VELOC.	PREC.	EVAP.	T. TOP	T. BOTTOM	WIND	VELOC.	PREC.	EVAP.
11	80	59	----	----	75	71	82	69	80	71	64	67	78	71	71	68	67	66	Se	Lt	0	0	72	67	Sw	Lt	----	.1
12	87	78	----	----	67	66	95	66	82	75	80	72	77	75	91	74	69	68	Sw	Lt	----	.1	74	69	Sw	Lt	----	.1
13	83	70	----	----	75	73	91	72	81	75	76	73	75	72	86	71	72	71	0	0	Lo st		74	72	Se	M	----	.4
14	83	70.5	----	----	71	70.8	98	71	80	75	79	73	78	73	79	71	74	69	0	0	0	0	73	70	Se	Lt	----	.15
15	83	67	----	----	70.5	70.5	100	70.5	79	76	87	75	68	66.5	93	66	72	71	0	0	0	0	73	71	Sw	St	1.5	----
16	83	63	----	----	66	65	95	64	81	74	72	71	74	69	78	67	73	72	Se	Lt	Lo st		75	73.5	Se	Lt	----	.3
17	73	62	----	----	67	64	85	62	65	63	90	62	71	69	90	68	73	73	0	0	----	.1	73	73	Se	M	hvy	----
18	75	62	----	----	64	64	100	64	74	71	86	70	68	66	90	65	72	71.5	Sto	rm	hvy	----	71	71	----	----	hvy	----
19	72	52	----	----	64	63	95	62	64	61	85	59	63	61	89	60	70	69	----	----	----	.1	70	69	----	----	----	.2
20	74	53	----	----	57	56	94	55	70	65	77	62	69	63	72	59	68	68	----	----	0	0	71	70	----	----	----	.2
21	77	54	----	----	60	58	89	57	Lo st				63	61	89	60	69	69	0	0	0	0	70	70	----	----	----	lost
22	81	53	----	----	64	61	85	59	79	71	68	67	72	67	78	64	70	69	0	0	----	.1	71	70.5	----	----	----	lost
23	84	59	----	----	62	61.5	97	60	80	74	76	72	74	71	86	70	70	69	S	M	T	----	73	71	----	----	----	.2
24	67.5	63	----	----	63	63	100	63	68	66	90	65	64	62	90	61	71	70	----	----	0	0	71	70	Ne	St	----	.1
25	66	57	----	----	59	58	94	57	Lo st				64	62	90	61	70	69	----	----	----	.1	69	69	----	----	----	.1
26	68	56	----	----	60	59	94	58	67	64	81	62	62	62	100	62	68.5	68	Se	Lt	----	.1	68	66	----	----	.3	----
27	78	61	----	----	68.1	67.9	99	68	77	75	79	74	71	70	95	70	69	68	0	0	----	.1	70	70	----	----	.2	----
28	71	62	----	----	62	62	100	62	65	64 5	98	64	70	68	90	67	69	69	0	0	0	0	71	70	0	----	----	----
29	83	59	----	----	63	62	94	61	81	77	83	75	80	77	87	76	69	69	0	0	0	0	72	70	----	----	----	.1
30	83	68	----	----	69	68	95	68	79	76	87	75	75	73	91	72	72	70	0	0	0	0	75	72.5	----	----	----	.15
31	75	64	----	----	66	65	95	64	70	68	90	67	74	73	95	73	74	73	0	0	----	.15	75	73.5	----	----	----	.5

St -strong. M—Medium. Lt—Light wind.